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ASTRONOMY AND ASTROPHYSICS

NGC 7139 and its stellar neighbourhood

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Summary. Photographic photometry and a rough spectral classification were carried out for many stars in the angular vicinity of the planetary nebula NGC 7139. The extinction-distance method was applied and led to a distance of 2.4^{+600}_{-800} kpc for the planetary. Several highly reddened early-type stars appear to be located beyond the Perseus arm.

In the [O III] 5007 Å line, observations of NGC 7139 with a Fabry-Pérot interferometer led to an expansion velocity of 20 km s^{-1} and a heliocentric radial velocity of -73.3 ± 3 km s^{-1}.

Key words: planetary nebula: distance – velocities; galactic structure: distant stars

1. Introduction

Reliable distances are still not available for the vast majority of planetary nebulae (PN). Spectroscopic parallaxes are applicable to those few objects, where central stars have a measurable companion. The extinction-distance method, based on stars around a PN, is generally accepted as the second-best method. For local PN, trigonometric parallaxes of their central stars determined with the Hubble Space Telescope will also lead to promising distance data in future.

In the case of NGC 7139 that lacks a visible companion star and is certainly too far away for the trigonometric parallaxes mentioned, only methods (particularly the Shklovskij method) which result in typical distance errors of a factor 2, have been applied. The extinction-distance method (EDM) thus appears to be the only way for deriving a reliable distance and consequently was employed by us.

In addition to spectroscopic observations in the [O III] 5007 Å line, we describe the results of our application of the EDM (by means of photographic *UBV* photometry and rough spectral classification), which not only led to an improved distance for the nebula, but also to an unexpected outcome with respect to the galactic structure.

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2. Observations

Our *UBV* photometry uses plates taken with the Schmidt camera (134 cm clear aperture) of the Karl Schwarzschild Observatory in Tautenburg and with the Schmidt telescope (105 cm) of the Tokyo Astronomical Observatory at Kiso. With the former instrument, 2 *U*(ZU 21 + UG 2), 3 *B*(ZU 21 + GG 13), and 2 *V*(103 a-D + GG 11) plates were obtained in May 1983, centred half-way between the open cluster NGC 7142 (which served as standard sequence) and NGC 7139. In Nov. 1984 and March 1985 altogether 1 *U*(II a-O + UG 1), 2 *B*(II a-O + GG 385), and 1 *V*(II a-D + GG 495) plates were taken with the Kiso Schmidt; the Kiso standard area no. 115 was photographed for this purpose, since these plates were under use also for another program (Ishida and Weinberger, 1987).

A rough spectral classification of the majority of our stars was carried out by means of an objective prism plate (103 a-E emulsion; reciprocal dispersion ca. 2600 Å at Hγ) and a corresponding plate containing standards in SA 8, obtained at Tautenburg in May 1983.

The central (20″) part of NGC 7139 was observed in the [O III] 5007 Å line with a scanning Fabry-Pérot spectrometer (Hippelein and Münch, 1981) attached to the 1.23 m telescope on Calar Alto, Spain. The spectral resolution was chosen as 10 km s^{-1}; an RCA C 31034 Å photomultiplier served as detector. NGC 7027 was used as a standard.

3. Measurements

As can be judged from the POSS blue-sensitive prints, the projected star density within 10′–15′ radius around NGC 7139 ($\alpha = 21^h44^m.6$, $\delta = +63°.4$; $l = 104°.0$, $b = +7°.8$) is homogeneous. A larger complex of dust is present in the south-west and west, and smaller ones in the south-east and north, all at distances of $\gtrsim 0°.5$. About 20′ to the east, very faint nebulae commence.

As a first step, we measured stars in the region within 10′ around the planetary and later we investigated stars in a field of similar size, 30′ away in the north-west. The latter field (centred at $\alpha = 21^h41^m$, $\delta = +63°.9$), as to star density and homogeneity, appears very similar to the first one, so that a similar extinction vs. distance relation could be expected.

A preselection of stars was carried through before we started the irisphotometer measurements. By comparing *U* and *B* plates, we singled out the bluest and several of the reddest stars, in both fields altogether 260; we thus hoped to later use several of the blue

Table 1. Stars with spectral types ≦A0 and ≧G8 around NGC 7139

Star	V	$B-V$	$U-B$	$\langle\sigma_U\rangle$	$\langle\sigma_B\rangle$	$\langle\sigma_V\rangle$	Sp_{OP}	SP_{UBV}	M_V	$E(B-V)$	D
1	14.36	0.54	0.33	0.07	0.07	0.08	B7:	B9–A0	+0.4	0.59	2.59
2	15.39	0.85	0.11	0.06	0.03	0.07	B7	B3	−1.6	1.05	5.32
3	14.97	0.84	0.26	0.01	0.08	0.04	B8	B6–B7	−0.9	0.99	3.47
4	13.49	0.61	0.03	0.04	0.06	0.05	B7:	B5–B6	−1.1	0.78	2.62
5	16.20	0.79	0.44	0.06	0.03	0.07	B8:	B9	+0.1	0.87	4.61
6	12.64	0.27	0.24	0.03	0.02	0.05	B8[a]	A0[a]	+0.65[a]	0.27[a]	1.61[a]
7	12.40	1.74	2.11	0.07	0.03	0.06	K2:	K5–M2	−0.4	0.19	2.74
8	13.86	1.55	1.55	0.03	0.06	0.11	G8	K2–K3	+0.4	0.32	3.08

[a] Identical with star no. 405 of Kun (1982), who gives $V=12\overset{m}{.}45$, $B-V=0\overset{m}{.}22$, $U-B=0\overset{m}{.}25$, and a spectral type A0. Our $E(B-V)$ and D were derived by using V(mean) $=12\overset{m}{.}55$, $B-V=0\overset{m}{.}27$, and the type A0

stars as indicators for large distances and the red stars for medium ones.

The Tautenburg plates were measured with the irisphotometer in Innsbruck, the Kiso plates with the Kiso irisphotometer. The standard sequence stars were taken from van den Bergh and Heeringa (1970). The effects of colour equations were negligible for all Tautenburg plates, but were $B=b+0.09(B-V)-0.10$ and $V=v+0.14(B-V)-0.16$ for the Kiso plates, b and v being the instrumental magnitudes. In the end, only a fraction of the stars measured were useful for our purposes: the brightness of them was determined on all available plates, i.e., 3 in U, 5 in B, and 3 in V. Great carefulness has been applied during the measurements.

For most of the 260 stars estimates of their spectral types were feasible. At the dispersion reported above the classification necessarily had to be rough and also suffered from consequences of a different interstellar extinction for the stars in the standard field SA 8 and in the program fields. Anyway, the classification is reliable to one spectral class, perhaps even a bit better; this was quite sufficient to tell strongly reddened early-type stars from F and G stars (possibly with UV-excess), as is discussed below.

Details on the data reductions with respect to the Fabry-Pérot interferometer observations of NGC 7139 in [O III] are analogous to those described in Gieseking et al. (1986).

4. Data

In the UBV colour-colour diagram, a number of stars of both fields are located to the right of the main sequence hump and to the right of the reddening line of a B 3 star, roughly at $B-V\approx 1.0$ and $U-B\approx +0.1$. To consider such stars as heavily obscured early-type stars on the basis of the photometry alone would be dangerous, since all of them could perhaps be of F or G type, shifted to these positions by UV-excess, reddening and brightness errors. The objective prism spectra indeed show that several of the above stars are F or G stars, but – much more intriguing – they show that a number of them must in fact be B stars (behind appreciable obscuration)!

We proceeded as follows: only the objects classified as < A0 on the prism plates and ≥G 8 were taken into account. As will be discussed below, the latter can be rather reliably assumed to be of luminosity class III, whereas the former are assumed to be main sequence stars; the assumption of luminosity classes I or II for the early-type stars would place them at unreasonably high distances.

Due to the uncertainty of up to one class in the spectral classification, for the final derivation of spectral types (i.e., absolute magnitudes), the location of the stars in the colour-colour diagram was used, employing $E(U-B)/E(B-V)=0.72+0.05\,E(B-V)$ for the back-shifts. For the evaluation of the interstellar reddenings and distances $A_V=3.2\,E(B-V)$ and the colours and absolute magnitudes of Schmidt-Kaler (1982) were taken.

In Tables 1 and 2 the numerical results are presented for the field around NGC 7139 and the nearby one in the north-west of it. The tables list the star numbers, which correspond to those on the finding charts in Figs. 1 and 2; in the subsequent columns one finds magnitudes and colours, average mean errors, the spectral types determined from the prism plates (colons denote less certain data), UBV spectral types, absolute magnitudes, colour excesses derived from the colour-colour diagram (assuming main-sequence early-type stars and giant late-type stars), and the distances in kpc.

The $E(B-V)$ vs. D diagram for the stars of the above tables is given in Fig. 3. The small black squares represent those stars from the photographic work of Kun (1982) that are in our fields and to whom she had assigned spectral types and luminosity classes; in the case of star no. 684 (she gives KO V, $V=11\overset{m}{.}17$, $B-V=1\overset{m}{.}29$, $U-B=1\overset{m}{.}26$, resulting in an unreasonably high reddening), however, we assumed luminosity class III; moreover, the spectral types for Kun's stars that we used were the mean of her respective objective prism classification and the type which could be deduced from her colours in the colour-colour diagram, since the accuracies are comparable.

5. Discussion

Before evaluating the distance of NGC 7139, a discussion on some data of Tables 1 and 2 is necessary.

For the early-type stars (which are mostly strongly reddened), SP_{OP} are, on the average, somewhat later classified than SP_{UBV}. The essential classification criterion for the OP classification was the comparison of the red and blue continua, separated by the gap in green; since the standard stars were taken from the centre of field SA 8, where the high star density points to a rather high transparency, and the standards are brighter (i.e., nearer) than the program stars, such a discrepancy can indeed be expected. Moreover, at least for those stars with the greatest differences (no. 2 in Table 1, and nos. 6, 11, and 14 in Table 2), the discrep-

Table 2. Stars with spectral types ≦A0 and ≧G8 in the field north-west of NGC 7139

Star	V	$B-V$	$U-B$	$\langle\sigma_U\rangle$	$\langle\sigma_B\rangle$	$\langle\sigma_V\rangle$	Sp_{OP}	Sp_{UBV}	M_V	$E(B-V)$	D
1	14.08	0.66	0.06	0.01	0.04	0.04	B7	B5	−1.2	0.83	3.34
2	13.35	0.46	0.26	0.07	0.05	0.08	B7	B9–A0	+0.4	0.51	1.84
3	13.84	0.66	0.09	0.02	0.05	0.04	B7:	B6	−1.0	0.82	2.78
4	14.77	0.67	0.35	0.02	0.07	0.04	B8:	B9	+0.2	0.74	2.75
5	15.31	0.71	0.15	0.06	0.07	0.04	B8	B6	−1.0	0.86	5.15
6	13.39	0.65	0.01	0.08	0.04	0.03	B8:	B4–B5	−1.3	0.83	2.54
7	14.31	0.79	0.30	0.03	0.06	0.03	B8	B7–B8	−0.4	0.91	2.29
8	13.85	0.75	0.11	0.02	0.04	0.02	B7:	B4–B5	−1.3	0.92	2.77
9	13.67	1.63	1.57	0.06	0.02	0.01	G8	K2–K3	+0.4	0.42	2.43
10	14.97	0.82	0.26	0.09	0.06	0.04	B8	B6–B7	−0.8	0.96	3.47
11	16.21	0.92	0.05	0.03	0.06	0.03	B7	B1–B2	−2.6	1.17	10.33
12	14.46	0.74	0.19	0.02	0.02	0.06	B7	B6–B7	−0.9	0.89	3.18
13	13.40	1.65	1.67	0.08	0.03	0.09	–	K3	+0.3	0.38	2.38
14	15.84	0.83	0.08	0.07	0.06	0.06	B8	B3	−1.7	1.04	6.95
15	15.09	0.80	0.12	0.06	0.04	0.12	B7	B4–B5	−1.3	0.98	4.47

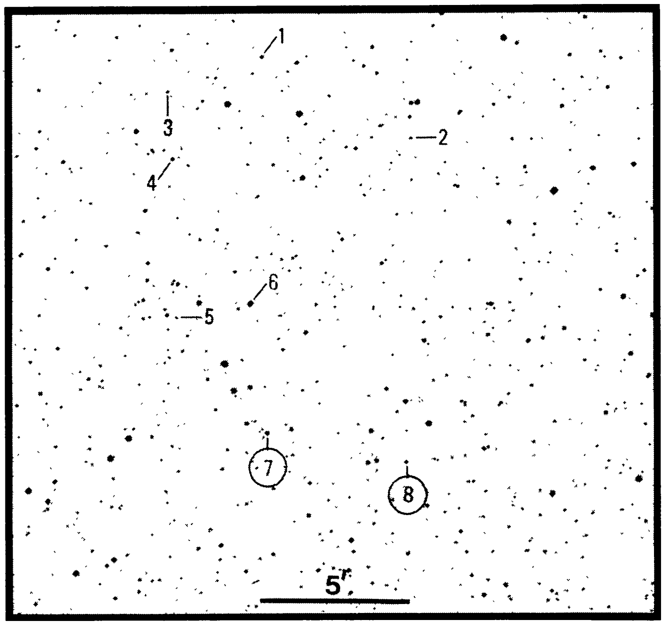

Fig. 1. The field around NGC 7139, reproduced from a Tautenburg B plate. The marked stars represent those in Table 1; late-type stars are encircled

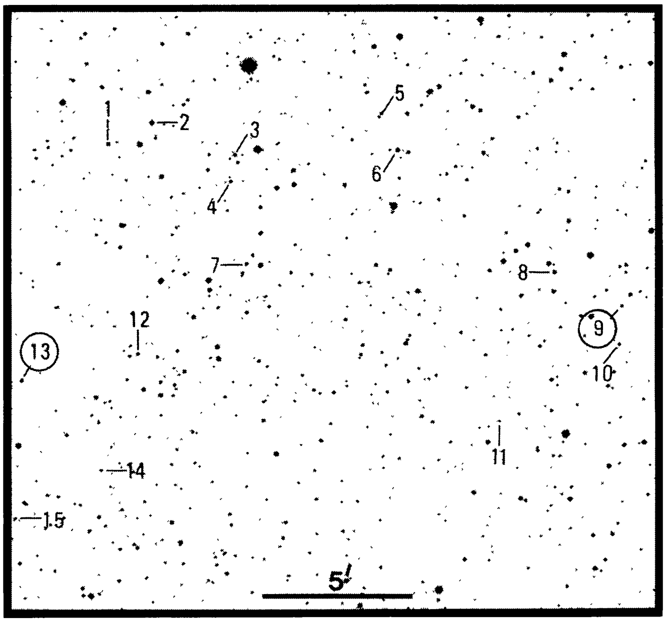

Fig. 2. The field around $\alpha = 21^h41^m$, $\delta = +63.^\circ9$, reproduced from a Tautenburg B plate. The marked stars represent those in Table 2; late-type stars are encircled

ancies can hardly be explained by shortcomings in the photographic photometry. For the few late-type program stars (which are rather bright), the SP_{OP} are a bit earlier than the SP_{UBV}.

It might appear suspicious that there are twice as much B-stars in the north-western field (13) than around 7139, although both fields are of same size and have a similar star density. A comparison of the tables and Figs. 1 and 2, however, clarifies the point: in the field around the PN (note: the originally measured stars were rather uniformly distributed across the field) B-stars entirely avoid the region south of the nebula; presumably, there is some outlying dust responsible for that. By the way, Kimeswenger (1987) very recently investigated a field of the same size directly adjacent to the north of the north-western field with the same method and also found 13 B-stars, thus substantiating our reasoning.

5.1. Distance of NGC 7139

In their Table 3, Sabbadin et al. (1985) have accumulated many distance estimates for this planetary taken from the literature, and in their Table 2 also report on an "individual distance", based upon the mean extinction in the galactic disk. All these estimates range from 0.88 to 1.81 kpc. An independent distance estimate may now be obtained by means of Fig. 3. For this purpose, we use $c = 0.54 \pm 0.20$ (Kaler, 1983), which corresponds to $E(B-V) = 0.^m37 \pm 0.^m14$.

It is obvious from the figure that for the distance estimate we run into difficulties for the lower reddening limit. For $0.^m37 \leq E(B-V) \leq 0.^m51$ a rather reliable distance can be inferred, but before we have to discuss the relevant parts of Fig. 3 in some detail.

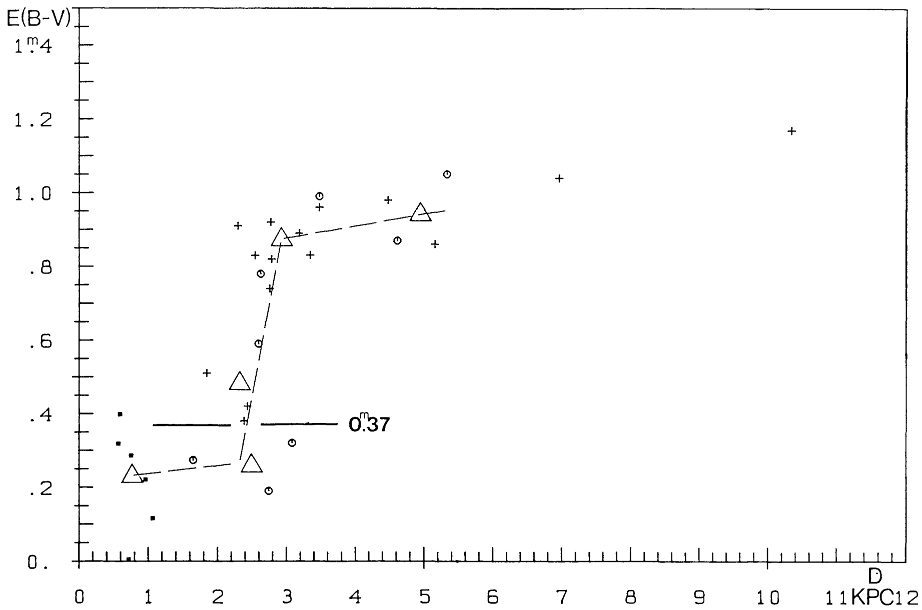

Fig. 3. The reddening vs. distance relation. Circles or crosses correspond to the stars of Tables 1 and 2, respectively. Small black squares represent stars taken from Kun (1982). Large triangles denote the centres of the various groups of stars. $E(B-V)=0^{m}.37$ is the interstellar extinction in front of NGC 7139

We notice that the use of the stars of both fields is justified; at least, the omission of the stars of the northwestern field would hardly change the $E(B-V)$ vs. D relation. In addition, the stars in the above described field investigated by Kimeswenger (1987) show a nearly identical course.

The reliability of the stars at and near the break at $D \approx 2.3$ kpc must be proved. The lefternmost circle corresponds to the only star common to Kun (1982) and us, and would be shifted to $E(B-V)=0^{m}.30$ and $D=2.05$ kpc if of luminosity class III, thus scarcely changing anything. A higher luminosity strongly contradicts the reddening course. For all the other stars assumed to be of luminosity class III, other luminosities can be practically excluded because of their location in the colour-colour diagram, the objective prism spectra, and the $E(B-V)$ vs. D relation of the residual stars in Fig. 3.

One further star deserves critical examination – the one at $D \approx 600$ pc, but exhibiting a reddening higher than the PN. First, its location is physically questionable with respect to the other points at moderate distances according to Fig. 3. Second, the star is in the south-east of the nebula, where blue stars seem to lack (higher obscuration?). Third, the modest accuracy of the photographic photometry might influence the location. Fourth, out of the 6 stars taken from Kun (1982), the closest one to the PN, at $2'.5$ to the east, is our common star, having $E(B-V)=0^{m}.27$, distinctly less than the star under discussion.

The limited accuracy of photographic photometry is the reason for defining cluster centres (the triangles in Fig. 3) for several groups of stars. The broken line in the figure is based on these values. A rather satisfying extinction-distance relation could thus be set up.

Consequently, the distance of NGC 7139 amounts to 2.4 kpc. The distance cannot be larger than the well-defined cluster of stars at $E(B-V) \approx 0^{m}.9$ and $D=2.9$ kpc – even the presence of a few stars of luminosity class III there would insignificantly shift the cluster centre to, say, ~ 3 kpc. A lower limit can only be roughly estimated, but it will hardly be less than the distance of the "common" star, i.e., 1.6 kpc. All these values are only valid, if the reddening for the PN is not distinctly lower than the reported $E(B-V)=0^{m}.37$, of course.

In short, we take as a final distance $D = 2.4^{+600}_{-800}$ kpc for NGC 7139, which should be more reliable than previous distance estimates. This distance is substantially larger than all earlier determinations, but still within the generally accepted error limits of a factor 2 for statistically derived distances. At 2.4 kpc, the mean harmonic diameter of NGC 7139 (78″) corresponds to a linear diameter of 0.91 pc, a quite reasonable value. Clearly, it would be of considerable value to i) better evaluate the reddening of NGC 7139 and ii) to observe the relevant stars, in order to get more accurate brightness data and to find out their luminosities.

5.2. Highly reddened distant stars?

As distant stars we denote those six objects located at $D \geqq 4.5$ kpc according to Fig. 3.

We start our discussion by first referring to the cluster of stars (all of type B) centred at $D=2.9$ kpc and $E(B-V) \approx 0^{m}.9$. This distance would place them at the inner edge of the Perseus arm, which is at $D=3.2$ kpc and 2.8 kpc at $l=100°$ and $l=110°$, respectively (Gerasimenko, 1983). A higher luminosity than the assumed one for a few of them would not change this outcome.

The cluster is followed by a gap with $\Delta D \approx 1$ kpc, a small group of stars at $D \approx 5$ kpc, slightly more obscured than the previous one, and two further outlying stars.

Having $b \approx +8°$ in mind (corresponding to $z=0.7$ kpc at $D=5$ kpc), the existence of several B stars far above the galactic plane appears, a priori, questionable. There are, however, several authors which postulate material located distinctly above the plane at large distances and at the galactic longitudes of interest here. Of special interest are the 21 cm observations of Verschuur (1973), who postulates an α-arm at a distance of 5–6 kpc (for $l=104°$), reaching up to $b > +10°$. Such a "warp" might be the result of the gravitational attraction of the Magellanic clouds (Davies, 1982).

A distinct deviation from the galactic plane, starting at $v \approx -60\,\mathrm{km\,s^{-1}}$ and reaching $b \approx +12°$ at velocities of about $-120\,\mathrm{km\,s^{-1}}$ can furtheron be seen in the (v, b) map of Burton (1985) (at $l=108°$, for example). A schematic view of the warped

H I-gas disk is e.g., also given in Fig. 3 of Ichikawa and Sasaki (1984).

An independent argument for material distinctly above the galactic plane are the hints to distant stars at $z \gtrsim 0.5$ kpc in areas near to NGC 7139: Kun's (1982) stars nos. 216 and 1071, at $l = 106\overset{\circ}{.}0$, $b = +6\overset{\circ}{.}6$ and $102\overset{\circ}{.}5$, $b = +5\overset{\circ}{.}8$, respectively (classified as B0 stars by her, and as OB⁻ in the Luminous Star Catalogue) would be 5.1 kpc and 5.6 kpc distant, if assumed to be on the main sequence. HD 210040, at $l = 104\overset{\circ}{.}9$, $b = +5\overset{\circ}{.}3$ (HD type: A 3) shows an O-type spectrum (with He II 4686 Å in emission) according to Kun (1982) and was classified as O5e by her; this star (no. 1501), using Kun's brightness data and assuming it as a main sequence object, would be 5.2 kpc distant. Furthermore, a faint star ($m_V = 12.4$) close to HD 210040 is classified as O5 in the AGK 3 catalogue (+62 1304) and correspondingly would be extremely distant. The list of such stars could be continued.

In this connection, it should be mentioned that early-type stars which were born even at high galactic latitudes are no more regarded as fancies (Keenan et al., 1987). In our case, the warp in the direction of interest might provide an explanation for the occurrence of possible early-type star candidates distinctly outside the galactic plane.

Stars at $D > 5$ kpc are beyond the generally accepted boundaries of the Perseus arm at these galactic longitudes. Thus, their location might reflect the existence of structures behind the Perseus arm. To further investigate this suspicion, Kimeswenger (1987) started a master thesis, where he collected literature data on spiral arm tracers between $90° \leq l \leq 180°$ and carried through photographic photometry + a rough objective prism classification of stars in two small fields 45′ and 100′ to the north of NGC 7139. The application of a uniform reduction to all these data [using, e.g., $A_V = 3.0\ E(B-V)$] led to surprising results: Behind the well defined Perseus arm there is a distinct narrow zone nearly devoid of spiral arm tracers in the whole second quadrant; farther out, he found ~100 tracers, which he interprets as indications for an arm. His results for the two small fields fit together with these data. Of interest for our results is, that the gap in Fig. 3 (when $R = 3.0$ would be taken) is at the same location as the above discussed gap and the $E(B-V)$ vs. D relation for both of his fields is also very similar to the one shown in Fig. 3.

To sum up for our stars: although the shortcomings in photographic photometry can result in dangerous conclusions (if the OP-spectral classification would be correct, our stars beyond the Perseus arm would vanish) we suppose that distant, highly reddened stars exist at about the galactic coordinates of NGC 7139. Confirmations are badly wanted.

5.3. Expansion and radial velocities of NGC 7139

Since this planetary belongs to the rather sparsely investigated objects, at least in the sense of spectroscopic observations, we want to add information on the expansion and radial velocities, the more, because expansion velocities V_{exp} are of interest in context with linear radii. For large PN to which NGC 7139 might belong, recent measurements yielded a much lower average V_{exp} than for the residual objects (Gieseking et al., 1986). In Fig. 4 the [O III] 5007 Å line profile is presented.

To interpret the double, bowed appearance as a result of the nebula's expansion is not as obvious as it seems, because it might, in principle, be a clump of gas with high negative velocity. A number of such examples exist in other planetaries. Considering the smooth distribution of the surface brightness as apparent on the POSS blue-sensitive print or on Tautenburg plates, the double structure, however, indeed appears to reflect the expansion.

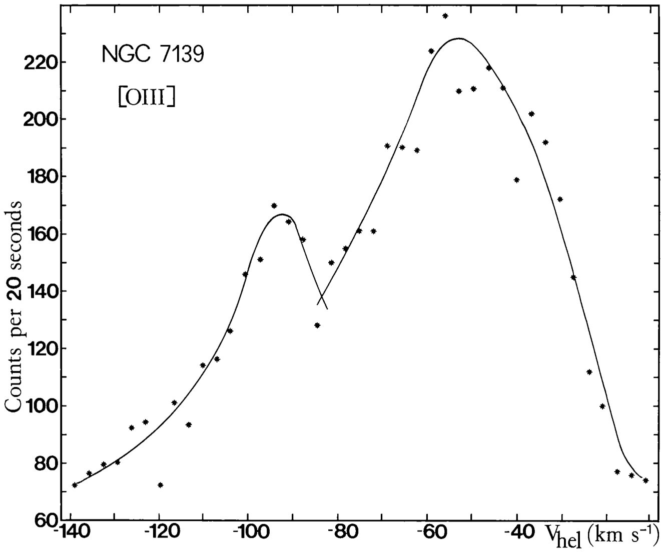

Fig. 4. The central part (20″) of NGC 7139 as observed with a Fabry-Pérot interferometer (1.2 m telescope) in the [O III] 5007 Å line.

One determination of V_{exp} was carried out before: Sabbadin et al. (1985) found $2\ V_{exp} = 38$ km s^{-1}. From the separation of the red-shifted and blue-shifted components in Fig. 4 we find $2\ V_{exp} = 40$ km s^{-1}. This value also harmonizes with the data in the plot of V_{exp} vs. linear radii of Gieseking et al. (1986).

Less straightforward is the determination of the radial velocity V_{hel}. According to Schneider et al. (1983), there exists a rather old, very inaccurate value and an obviously reliable one, derived by them from two spectra, taken with a reciprocal dispersion of 26 Å by using 3 lines: $V_{hel} = -54.1 \pm 2.5$ km s^{-1}. At our resolution the question is, where to define V_{hel}: if we take the mean between the red-shifted and blue-shifted components, we get $V_{hel} = -73.3$ km s^{-1}. If we divide the area under the curve in two equal parts, we get -60.0 km s^{-1}, both with an estimated error of $\sim \pm 3$ km s^{-1}. From a physical point of view, we favour the former value.

6. Conclusions

By means of photographic UBV photometry and objective prism classification 260 stars in two small fields, one including the planetary nebula NGC 7139, the other one $0\overset{\circ}{.}5$ away, were investigated. Altogether two dozen stars, mostly of spectral type B, and a few late-type stars were extracted. The set-up of an interstellar reddening vs. distance diagram for all these stars resulted in a rather well defined relation. From this relation, it was possible to derive a distance $D = 2.4^{+600}_{-800}$ kpc for the planetary, which should be more reliable than previous estimates.

An unexpected characteristic of the reddening vs. distance diagram was the existence of several very distant, highly reddened B stars. Although this outcome is supported by Kimeswenger (1987), it should be considered premature unless a confirmation by other methods is available.

For the planetary nebula, also the expansion and the radial velocities were determined using a Fabry-Pérot-interferometer on the 1.2 m Calar Alto reflector: the value of $2\ V_{exp} = 40$ km s^{-1} agrees well with the only previously determined value, whereas $V_{hel} = -73$ km s^{-1}, which seems to be the more appropriate one of two evaluations, is in contradiction to the (sparse) literature data.

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